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Title: THE MTI DATA REFERENCE GUIDE FOR LEVEL 1 IMAGERY

Author(s): William B. Clodius, NIS-2

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Draft
The MTI Data Reference Guide for Level 1 Imagery

William B. Clodius
NIS-2, MS-323, Los Alamos National Laboratory,
Los Alamos, NM 87545
Phone: (505) 665-9370
Fax: (505) 667-8315
Email: wclodius@lanl.gov

Introduction

The Multi-spectral Thermal Imager (MTI) ground imagery data will be provided in several forms, but currently access is restricted to the two Level 1 products, level1b_u (unregistered calibrated data) and level1b_r_coreg (co-registered calibrated data). Each product is accompanied by associated header files with data useful in interpreting the specific images incorporated in the product.

The data products and one version of the header file are hierarchical data files (HDF) (http://hdf.ncsa.uiuc.edu/) created using Interactive Data Language (IDL) (V5.3) of Research Systems Incorporated (RSI) routines that claim support of HDF version 4.0. The contents of the files are described in detail in the text files, README_mti_header.txt, README_level1b_u.txt, and README_level1b_r_coreg.txt, which accompany the distribution. A general text document, README, will also accompany an official distribution. The README identifies any restrictions on data distributions, and identifies points of contact for information related to the MTI data. Copies of the above text documents, as distributed at the time this document was written, are included in the appendix. Users are advised to always rely on the versions that accompany their data in interpreting the data files, identifying useful points of contact, and in understanding the restrictions on the data distribution.

The main data contained in the level1b_u and level1b_r_coreg products is their imagery. This paper provides an overview of the imagery that may be useful to users. This imagery exhibits a number of artifacts related to the processing of the raw MTI data and not inherent in the scene being imaged. In order to understand the imagery it is useful to understand these artifacts and the part of the file structure containing the imagery. The artifacts in turn require some knowledge of the focal plane design and of typical system operations. This paper will therefore proceed in the order focal plane design, satellite operations, header file, level1b_u image file structure, level1b_r_coreg image file structure, artifacts flagged by the quality images, calibration artifacts, and registration artifacts. A briefer summary of the artifacts can be found in the files README_data_caveats.pdf and README_data_caveats.txt, which accompany your distribution and respectively provide Adobe PDF and plain text versions of the same information.

Focal plane design

The MTI focal plane [Rienstra and Ballard, 1999] is of an unusual design. This design is reflected in the file structure of the level1b_u product and in some of the artifacts found in the level1b_u and level1b_r_coreg products. Of particular interest are the MTI bands and its implementation using three sensor chip assemblies (SCA).

The MTI system images in fifteen spectral bands (identified by the letters A-O) [Clodius et al, 1998]. However, the data is reported in terms of sixteen effective bands, because one spectral band, H, is duplicated (as H1 and H2) to improve its signal to noise ratio. Except for band O, the alphabetical sequence is in order of increasing wavelength. Band O was a late addition to the system design with wavelengths between those of band I and band J. Characteristics of the MTI bands are summarized in Table 1.

Table 1. The MTI band characteristics

Band	Wavelength Range (µm)	Detector Type	Description	Pixel Selection Available
A	0.45-0.52	Si-PIN	Blue "true color"	No
B	0.52-0.60	Si-PIN	Green "true color"	No
C	0.62-0.68	Si-PIN	Red "true color"	No
D	0.76-0.86	Si-PIN	VNIR vegetation	No
E	0.86-0.89	InSb	NIR water vapor reference	Yes
F	0.91-0.97	InSb	NIR water vapor	Yes
G	0.99-1.04	InSb	NIR water vapor reference	Yes
H1 & H2	1.36-1.39	InSb	NIR cirrus	No
I	1.54-1.75	InSb	SWIR surface	Yes
O	2.08-2.37	InSb	SWIR surface	Yes
J	3.49-4.1	InSb	MWIR surface	Yes
K	4.85-5.05	InSb	MWIR atmosphere	Yes
L	8.01-8.39	HgCdTe	LWIR atmosphere	Yes
M	8.42-8.83	HgCdTe	LWIR surface	Yes
N	10.15-10.7	HgCdTe	LWIR surface	Yes

The focal plane is implemented on three SCAs: SCA 1, SCA 2, and SCA 3. Each SCA acts as a separate push broom imager covering more than 35% of the total cross track field of view of the MTI system. SCA 1 covers the center of the field of view and under normal operations the outer edges of its imagery overlaps the inner edges of the imagery of SCA 2 and of SCA 3. However, a given band on SCA 1 images the overlapping region, at a slightly earlier time and different angle than the corresponding portion of SCAs 2 and 3. In order to fit the readouts on the focal plane and have the highest spatial resolution bands as close as possible to the center of the focal plane, SCA 1 is rotated 180^{o} relative to SCA 2 and SCA 3. The bands on each SCA are, in order of increasing distance from the center of the focal plane, D, C, B, A, H, E, F, G, I, O, K, J, N, M, and L.

Within an SCA the bands are implemented using three detector technologies, Si-PIN, InSb, and HgCdTe. All detectors have twelve bit quantization. Si-PIN diodes are used to image bands A, B, C, and D, covering much of the spectrum from 0.45 to 0.87 microns. InSb diodes are used to image bands E, F, G, H, I, O, J, and K, which cover much of the spectrum from 0.87 to 5.2 microns. HgCdTe diodes are used for bands L, M, and N, covering much of the spectrum from 8 to 10.7 microns. Characteristics of the MTI detectors are summarized in Table 2.

Table 2. The MTI detector characteristics

Detector Type	Detector Pixel Size (µm)	Typical Nadir GSD (m)	Typical Off-nadir GSD (m)	Detector Pixels / SCA	Active Detector Pixels / SCA	Typical Scanlines / Image
Si-PIN	12.4	5	10	832	828	2497
InSb	49.6	20	40	208	207	625
HgCdTe	49.6	20	40	208	207	625

The Si-PIN diodes are 12.4 microns in size, and are implemented as two parallel rows of detectors, separated by an inactive region of 12.4 microns, with pixels alternating between rows. This implementation reduces eliminate detector cross talk on a cooled focal plane. The Si-PIN bands are implemented as 832 detectors on each SCA, but the last four detectors are always kept at the same voltage, so that only the first 828 detectors are active.

The InSb and HgCdTe detectors are 49.6 microns in size, and are all implemented as pairs of detectors on two parallel rows of detectors. Each row of the InSb and HgCdTe bands are implemented as 208 detectors, but the last detector is always kept at the same voltage, so that only the first 207 detectors are active. Except for band H, only one detector pixel of each pair can be read out at any one time. In band H the two rows are treated electronically as separate bands (H1 and H2), and both are read out, in effect improving signal to noise (S/N) through a form of time delayed integration. In principle, the combination of active elements is arbitrarily selectable, so that bad pixels can be avoided. However that capability has rarely been exercised, as the response of a pixel depends not only on which one of its pair has been selected, but which ones of its neighboring pairs has been selected. It was impractical to test all combinations of pixel selections in the ground calibration campaign, and extensive calibration data exists only for the two combinations (termed primary and alternate) with all pixels in a row selected. Therefore, except for a few experimental images, the selected pixels are exclusively from the primary row to minimize calibration problems.

In principle, a large variety of combinations of bands and SCAs can be selected as active, and the number of scan lines acquired in each active band is also selectable. In practice all three SCAs are kept active, and only a few band combinations have been used. Almost all imagery involves one of two combinations: all bands active (typical for day imaging), or only bands J-N active (typical for night imaging). The number of scan lines acquired is variable, but is almost invariably chosen so that all bands are expected to cover the same area. The vast majority of images also are further constrained to have 2497 scan lines for A-D, and 625 scan lines for E-O, yielding along track sampling comparable to cross track sampling.

Satellite operations

The MTI system has great flexibility in terms of operations [Kay et al, 1999], but not all of that flexibility has been exercised, and not all of the flexibility that has been exercised is of interest to the user of the imagery. Some aspects of its operations that are of obvious interest to the users are discussed below.

The MTI system has great flexibility in its pointing. Such rotation during an acquisition can cause the ground track of the image to follow an almost arbitrary (very rapid changes are impractical) direction with respect to the satellite motion, and can cause the projection of the linear detector arrays on the ground to be oriented arbitrarily with respect to the ground track. Such arbitrary ground tracks and array orientations can be found in a few experimental images, and images associated with incorrect pointing commands. However the vast majority of ground images fall into one of two categories: “nadir” where the satellite is within about 20^o of zenith of the image location, and the zenith angle is near a minimum, and “off-nadir” where the satellite is about 50^o-60^o of zenith of the image location. An off-nadir image is almost always preceded by a nadir image. In both nadir and off-nadir images the ground track is roughly parallel to the ground track of the satellite, and the arrays are oriented perpendicular to the ground track. For that reason this document will follow the convention that that the image sampling direction (row) associated with a single scan line will be termed the cross track direction, and the image sampling direction (column) associated with a single detector pixel will be termed the along track direction.

The detector pixel instantaneous field of view (IFOV) and cross track ground sampling distance (GSD) depends on the detector size, and the satellite’s altitude and orientation. The IFOV and GSD for the InSb and HgCdTe detectors are four times that of the Si-PIN detectors. For the current data, the cross track IFOV and GSD for the Si-PIN bands near nadir are about 6 m, and off-nadir are about 9 to12 m. The along track GSD depends on the satellite velocity and rate of rotation. For the vast majority of images, the rate of rotation is chosen so that the along track GSD approximates the along track detector pixel IFOV, i.e., about 6 m near nadir and 15 to 25 m off-nadir.

Until November 1, 2000 the MTI system had an on-board calibration system (OBCS) with several sources that cover the solar reflection bands, A-I and O, and the thermal infrared bands, J-N. Until that date every external image had associated with it appropriate collateral “images” of these sources. In order to organize the processing of these images, images that were close in time, including first and second looks at a ground site and all collateral looks at the OBCS sources, were grouped together for processing as an image sequence. All state of health data available during a sequence was recorded.

On November 1, 2000 a fuse connecting the control box for the OBCS to the main bus failed during an imaging sequence involving a focus adjustment. The OBCS will not resume operation. While the imaging system is working, subsequent images will not be accompanied by collateral OBCS data. Images acquired subsequent to this date will rely on more frequent deep space looks, as a substitute for the OBCS retro-mirror looks. In particular, an image sequence now consists of one or more external looks at the ground bracketed by deep space looks. Other aspects of the calibration will rely on the ground calibration data, historical on-orbit OBCS data, and vicarious calibrations. Preliminary analyses of bands A-D suggest the focus has also slightly degraded as a result of this failure.

MTI header file

The header file comes in two versions, an HDF file and a text file. The two files contain the same information. The HDF version has the naming scheme mti_header_*.gnd.hdf.v#. The text version has the naming scheme mti_header_*.gnd.txt.v#. In both naming schemes * is a seven digit number with leading zeros representing the image identifier (ID) used internally in the processing, and # is a two digit number (currently with a leading zero) indicating the file version number.

The header file contains ancillary information often useful in the interpretation of the main data products. This information includes, but is not restricted to, the detailed operating conditions of the focal plane, the geographical location of the image, and the location of the satellite during the image acquisition. Information on data contained in the header file is contained in the README_mti_header.txt file that accompanies the distributed data. As noted above, a copy of the README_mti_header.txt, as distributed at the time this document was written, is included as part of the appendix. Users are advised to always rely on the version that accompanies their data in interpreting the data files.

Level1b_u data files

The level1b_u files have the naming scheme level1b_u_*.gnd.hdf.v#, where * is a seven digit number with leading zeros representing the image identifier (ID) used internally in the processing, and # is a two digit number (currently with a leading zero) indicating the file version number. At the time of this memo only the most recent version of the level1b_r_u product are available.

The level1b_u product has the following scientific data sets (SDS) that contain the image data normally of greatest interest to the user:

- visImage_SCA#, where # is one of 1, 2, or 3, contains the calibrated radiances of SCA-# in bands A, B, C, and D. These SDSs will be present if and only if any of the bands A-D are active, e.g., it will be present in most day images, but will not be present in most night images. If present, these SDSs are 32 bit float arrays dimensioned as 832 (the number of acquired, not active, detector pixels) by the number of visible scan lines by 4 (the number of Si-PIN bands), where the bands are stored in the order A, B, C, and D.
- irImage_SCA#, where # is one of 1, 2, or 3, contains the calibrated radiances of SCA-# in bands E, F, G, H, I, O, J, K, L, M, and N. These SDSs will be present if and only if any of these bands are active. If present, these SDSs are 32 bit float arrays dimensioned as 208 (the number of acquired, not active, detector pixels) by the number of IR scan lines, by 12 (the number of electronic InSb and HgCdTe bands), where the bands are stored in the order of increasing wavelength, e.g., E, F, G, H1, H2, I, O, J, K, L, M, N. The third dimension is 12 even if some bands are not active, e.g., for night images inactive data is padded with zeros.
- visQuality_SCA#, where # is one of 1, 2, or 3, is a byte (8 bit unsigned integer) array of the same size visImage_SCA#. These SDSs will be present if and only if the corresponding visImage_SCA# is present. The values in visQuality_SCA# can be considered as containing flags (encoded as bit settings) indicating potential problems with the corresponding elements of visImage_SCA#.

- irQuality_SCA#, where # is one of 1, 2, or 3, is a byte (8 bit unsigned integer) array of the same size irImage_SCA#. These SDSs will be present if and only if the corresponding irImage_SCA# is present. The values in irQuality_SCA# can be considered as containing flags (encoded as bit settings) indicating potential problems with the corresponding elements of irImage_SCA#.

The structure of the above SDSs is summarized in Table 3.

The discussion of level1b_u artifacts will be confined to the imagery SDSs. Information on additional level1b_u SDSs of interest to the specialized user can be found in the README_level1b_u.txt file that accompanies the distributed data. As noted above, a copy of the README_level1b_u.txt as distributed at the time this document was written is included as part of the appendix. Users are advised to always rely on the version that accompanies their data in interpreting the data files.

Table 3. SDS image structures in level1b_u HDF files.

SDS	Data type	Column number (pixels)	Columns of active data	Typical number of rows	Number of bands	Band order
visImage_SCA1, visImage_SCA2, visImage_SCA3	32 bit float	832	828	2497	4	A, B, C, D
irImage_SCA1, irImage_SCA2, irImage_SCA3	32 bit float	208	207	625	12	E, F, G, H1, H2, I, O, J, K, L, M, N
visQuality_SCA1, visQuality_SCA2, visQuality_SCA3	8 bit integer	832	828	2497	4	A, B, C, D
IrQuality_SCA1, irQuality_SCA2, irQuality_SCA3	8 bit integer	208	207	625	12	E, F, G, H1, H2, I, O, J, K, L, M, N

Level1b_r_coreg data files

The level1b_r_coreg files are the output of an automated image registration procedure that maps the level1b_u imagery to a two dimensional grid defined on the WGS 84 ellipsoid [Leick, 1990]. By default one of the coordinates is aligned with the satellite ground track and the other coordinate is orthogonal to the ground track coordinate. These files have the naming scheme level1b_r_coreg_*.gnd.hdf.v#, where * is a seven digit number with leading zeros representing the image identifier (ID) used internally in the processing, and # is a two digit number (currently with a leading zero) indicating the file version number. At the time of this memo only the most recent version of the level1b_r_coreg product are available.

The level1b_r_coreg product has the following scientific data sets (SDS) that contain the image data normally of greatest interest to the user:

- visImage contains the calibrated radiances of bands A, B, C, and D as registered to a ground coordinate grid oriented parallel to the satellite motion. The GSD in this grid is the same in along track and cross track dimensions. This SDS will be present if and only if any of the bands A-D are active, e.g., it will be present in most day images, but will not be present in most night images. If present, this SDS is a 32 bit float array dimensioned as the number of cross track samples by the number of along track samples, by 4 (the number of Si-PIN bands), where the bands are stored in the order A, B, C, and D.
- visLoImage contains the data in visImage as registered to a ground coordinate grid oriented parallel to the satellite motion, with a GSD of four times that of visImage. This SDS is generated by defining the grid points to be at the centers of blocks of four by four pixels in the visImage and taking the mean

value of those blocks. This grid is identical with that of irImage and facilitates coregistration of the data for bands A-D with that in irImage. This SDS will be present if and only visImage is present. If present, this SDS is a 32 bit float array dimensioned as the number of cross track samples by the number of along track samples, by 4 (the number of Si-PIN bands), where the bands are stored in the order A, B, C, and D.

- irImage contains the calibrated radiances of bands E, F, G, H, I, O, J, K, L, M, and N as registered to a ground coordinate grid oriented parallel to the satellite motion, whose grid points are at the centers of blocks of four by four pixels in the visImage (if visImage is present). Its GSD is typically four times that of visImage This SDS will be present if and only if any of these bands are active. This SDS is a 32 bit float array dimensioned as the number of cross track samples by the number of along track samples, by 12 (the number of electronic InSb and HgCdTe bands), where the bands are stored in the order of increasing wavelength, e.g., E, F, G, H1, H2, I, O, J, K, L, M, N. The third dimension is 12 even if some bands are not active, e.g., for night images inactive data is padded with zeros.
- visQuality is a byte (8 bit unsigned integer) array of the same size visImage. This SDS will be present if and only if the corresponding visImage is present. The values in visQuality can be considered as containing flags (encoded as bit settings) indicating potential problems with the corresponding elements of visImage.
- vis_Lo_Quality is a byte (8 bit unsigned integer) array of the same size visLoImage. This SDS will be present if and only if the corresponding visLoImage is present. The values in vis_Lo_Quality can be considered as containing flags (encoded as bit settings) indicating potential problems with the corresponding elements of Vis_Lo_Image. Its values are currently the union of all values in the four by four blocks in visQuality that correspond to the four by four blocks in visImage that are used to generate visLoImage.
- irQuality is a byte (8 bit unsigned integer) array of the same size irImage. This SDS will be present if and only if the corresponding irImage is present. The values in irQuality can be considered as containing flags (encoded as bit settings) indicating potential problems with the corresponding elements of irImage.

The structure of the above SDSs is summarized in Table 4.

Table 4. SDS image structures in level1b_r_coreg HDF files.

SDS	Data type	Typical number of columns	Typical number of rows	Number of bands	Band order
visImage	32 bit float	> 2500	> 2500	4	A, B, C, D
irImage	32 bit float	> 625	> 625	4	A, B, C, D
irImage	32 bit float	> 625	> 625	12	E, F, G, H1, H2, I, O, J, K, L, M, N
visQuality	8 bit integer	> 2500	> 2500	4	A, B, C, D
Vis_Lo_Quality	8 bit integer	> 625	> 625	4	A, B, C, D
irQuality	8 bit integer	> 625	> 625	12	E, F, G, H1, H2, I, O, J, K, L, M, N

The discussion of level1b_r_coreg artifacts will be confined to the above SDSs. Information on additional level1b_r_coreg SDSs of interest to the specialized user can be found in the README_level1b_r_coreg.txt file that accompanies the distributed data. A copy of the README_level1b_r_coreg.txt, as distributed at the time this document was written, is included as part of the appendix. Users are advised to always rely on the version that accompanies their data in interpreting the data files.

Quality artifacts

The visQuality_SCA# and irQuality_SCA#, in the level1b_u product, and the visQuality, vis_Lo_Quality, and irQuality, in the level1b_r_coreg product, are byte arrays of the same size at the corresponding radiance images within the products. The values in these SDSs are flags (encoded as bit settings to be described below) indicating potential problems with the corresponding elements of corresponding radiance image. The value for a pixel in the visQuality, vis_Lo_Quality, and irQuality arrays is the union of the quality values associated with the level1b_u radiance image pixels that contribute to the corresponding level1b_r_coreg radiance pixel. These quality flags are currently:

- SCA1 - if the first (one's) bit is set the data in the pixels is derived from a band segment on SCA 1.
- SCA2 - if the second (two's) bit is set the data in the pixels is derived from a band segment on SCA 2.
- SCA3 - if the third (four's) bit is set the data in the pixels is derived from a band segment on SCA 3.
- SATURATED - if the fourth (eight's) bit is set the A/D converter returned a value of 4095. This often occurs in H1 and H2, which are typically run at very high gain as saturation has minor impact on the usability of these bands. This can also occur in many solar reflection bands if the scene has significant sun glint.
- RED_CONF - if the fifth (sixteen's) bit is set the calibration of the data should be treated with reduced confidence. Examples of reduced confidence data include a radiance larger than the largest value in the calibration look-up table, data for which only one ground calibration radiance level was available so that non-linearities could not be removed, and data from a detector pixel identified as noisy.
- INTERP - if the sixth (thirtysecond's) bit is set the coresponding data in the calibrated image was interpolated from adjacent pixels. This can currently occur if the scan lines are missing due to a corrupted data packet, the corresponding detector pixel is dead, or appropriate calibration data was missing for the detector pixel.

At the present time two bits (the seventh and eighth) are unused by level 1 processing.

Calibration artifacts

Calibration artifacts show up most strongly in near uniform scenes, e.g., water surfaces and clouds, but with suitable processing can be detected in almost any scene. These artifacts show up both as differences in the average responses of the different segments (band on an SCA) of a band, but also as differences in the responses of individual detector pixels within a segment, and as ghosting due to cross talk. This discussion will focus only on the current calibration for images collected before the OBCS failure on November 1, 2000.

SCA differences

The radiometric calibration of the MTI data is based on the ground calibration data [Clodius et al, 1999]. This data included spectral response data, MTF, and optical distortion measurements, as well as broad spectral band (white body and black body) radiometry. The current calibration relies on the broad spectral band radiometry as interpreted using sample filter measurements by the vendor. The sources available for the calibration could not uniformly (to within the desired accuracy) illuminate the full focal plane. Therefore the broad spectral band radiometry was acquired in two different setups: one with the source uniformly illuminating SCA 1, the other with the source uniformly illuminating both SCA 2 and SCA 3. While the setups were examined in detail to identify and eliminate any sources of differences in focal plane illumination between the two setups, subsequent analysis suggests that such differences did occur and is a cause of differences in the calibrations of the SCAs. Some additional artifacts might be due to differences in the spectral responses of a band on the different SCAs, and to differences in look angles between the SCAs.

Table 5 and Table 6 illustrate these differences between the SCAs, by showing the responses of SCA 2 and SCA 3 relative to SCA 1 for different sources. Two types of comparisons are shown for each source; one is the ratios of the average response of the active detectors in each segment, the other is the ratio of the average responses for those active detector pixels that approximately overlap the detector pixels on the other SCA. For bands A-D the overlapping pixels are assumed to be the end 64 pixels, for bands E-O the overlapping pixels are assumed to be the end 16 pixels. Table 5 gives the relative responses of the solar reflection band segments (H1 and H2 are not included because calibration is of minor importance to those bands) to a cloud free open ocean scene (Image 32992) and the visible reflectance panel (VRP) OBCS source. The water scene differs from the VRP, in the solar reflection bands, in having lower overall radiance, significant spectral structure due to the intervening atmosphere, and different effective look angles for SCA 1 versus SCAs 2 and 3. Table 6 gives the relative responses of the thermal infrared band segments to a cloud free open ocean scene (Image 32992). Except for obvious calibration artifacts and low amplitude radiance oscillations from waves the water image is remarkably uniform in the solar reflection bands. There do appear to be some minor thermal gradients in the water surface image.

Table 5. Relative calibrated responses of the solar reflection band segments.

Band	Water SCA 2/ SCA 1 Segment	Water SCA 2/ SCA 1 Overlap	Water SCA 3/ SCA 1 Segment	Water SCA 3/ SCA 1 Overlap	VRP SCA 2/ SCA 1 Segment	VRP SCA 2/ SCA 1 Overlap	VRP SCA 3/ SCA 1 Segment	VRP SCA 3/ SCA 1 Overlap
A	0.920	0.917	0.914	0.913	0.991	0.990	0.991	0.988
B	0.976	0.970	0.911	0.932	0.976	0.978	0.976	0.976
C	1.002	1.002	0.989	0.986	0.987	0.989	1.005	1.002
D	0.995	0.998	0.974	0.977	0.988	0.989	0.995	0.992
E*	1.018	1.083	0.987	0.982	0.982	1.076	0.963	0.963
F*	0.992	1.055	0.977	0.969	0.987	1.079	0.961	0.959
G*	0.999	1.033	0.969	0.971	0.989	1.056	0.949	0.952
I	1.000	1.007	1.018	1.004	0.938	0.943	0.958	0.955
O	1.003	1.000	0.995	0.981	0.930	0.927	0.946	0.944

Table 6. Relative calibrated responses of the thermal infrared band segments.

Band	Water SCA 2/SCA 1 Segment	Water SCA 2/SCA 1 Overlap	Water SCA 3/SCA 1 Segment	Water SCA 3/SCA 1 Overlap
J	1.017	1.016	1.035	1.022
K	1.022	1.024	1.027	1.021
L	1.013	1.012	1.019	1.014
M	1.005	1.004	1.009	1.001
N	1.004	1.002	1.008	1.004

Detector pixel artifacts

The current calibration scheme differs between the solar reflection bands A-I and O, and the thermal infrared bands, J-N. The thermal infrared band calibration uses all applicable OBCS sources in the calibration: a retro-mirror to remove offset drifts, two black bodies intended for calibrating the focal plane, and an aperture black body intended for calibrating the full optical train. The black body data is used to modify the responsivity estimates from the ground calibration using a 3 point lookup table. This modification removes most artifacts except for small drifts since the retro-mirror collection, and small residual nonlinearities. The solar reflection band calibration at this time uses only the retro-mirror source to

* Bands E, F, and G on SCA 2 have calibration artifacts, to be described later, on blocks of pixels in the portion of the band segment that overlaps SCA-1 imagery.

remove offset drifts. Changes in detector response since the ground calibration are uncorrected for the solar reflection bands. Therefore the solar reflection bands typically have more detector pixel artifacts.

Detector pixel drift artifacts take two forms: changes that cover the whole band segment (e.g., due to filter changes on orbit) and highly localized changes (e.g., due to radiation damage or mechanical damage due to a thermal cycle). If non-uniformities in the source and residual ground calibration artifacts are negligible, the combined effects of both forms of detector pixel drifts can be estimated by comparing the individual detector responses to mean band segment response. A low order fit to the band segment response, as a function of detector pixel index, can be used to reduce artifacts from non-uniformities in the source and residual ground calibration artifacts, at the cost of reduced sensitivity to detector pixel drifts over the whole band segment. Standard deviations about this fit should be a measure of the effects of individual detector response drifts.

Table 7, Table 8, Table 9, and Table 10 show the effect of these detector pixel artifacts. Table 7 and Table 8 show the standard deviation about the mean response of the individual detector pixels relative to the mean source response of the segment. Table 9 and Table 10 give the standard deviation about a quadratic fit to source response of the segment. Table 7 and Table 9 give relative standard deviations of detector pixels in the solar reflection band segments to a cloud free ocean scene (Image 32992) and the visible reflectance panel (VRP) OBCS source. The water scene differs from the VRP, in the solar reflection bands, in having lower overall radiance, significant spectral structure due to the intervening atmosphere, and different effective look angles for SCA1 versus SCAs 2 and 3. Table 8 and Table 10 give relative standard deviations of the detector pixels in the thermal infrared band segments to a cloud free ocean scene (Image 32992).

Table 7. Relative standard deviations of detector pixel responses about the mean band segment response for the solar reflection bands.

Band	Water SCA 1 (%)	Water SCA 2 (%)	Water SCA 3 (%)	VRP SCA 1 (%)	VRP SCA 2 (%)	VRP SCA 3 (%)
A	0.457	0.585	0.574	0.288	0.254	0.323
B	2.683	1.019	3.622	0.162	0.096	0.124
C	1.491	1.532	1.583	0.182	0.103	0.141
D	1.734	1.478	1.538	0.118	0.109	0.157
E	1.463	2.349	1.312	0.245	3.020	0.301
F	1.554	2.385	1.455	0.257	3.975	0.235
G	1.509	1.526	1.301	0.530	2.586	0.228
H1	3.078	14.520	27.423	0.621	0.986	0.624
H2	3.089	5.638	31.876	0.674	0.992	0.625
I	1.785	1.438	1.720	0.256	0.578	0.237
O	2.016	1.624	1.604	0.765	0.326	0.236

Cross talk

Under certain operating conditions the bands can exhibit electronic cross talk. For example, Bands A-D are read out at four times the rate of the other bands, and one scan line of every four is read out in sync with those other bands. When the other bands have a large response, and the integration times for bands A-D is comparable to the time between readouts, this readout of bands A-D that is in sync with the readout of the other bands shows a systematic offset. This problem is greatest when some of the other bands saturate. Bands A-D are therefore normally operated at lower integration times to minimize this problem.

Bands H1 and H2 often exhibit ghosting which is currently attributed to electronic cross talk.

Table 8. Relative standard deviations of detector pixel responses about the mean band segment response for the thermal infrared bands.

Band	Water SCA 1 (%)	Water SCA 2 (%)	Water SCA 3 (%)
J	0.293	0.230	0.653
K	0.106	0.185	0.302
L	0.247	0.169	0.395
M	0.194	0.208	0.513
N	0.107	0.577	0.337

Table 9. Relative standard deviations of detector pixel responses about a quadratic fit as a function of pixel index to the band segment response for the solar reflection bands.

Band	Water SCA 1 (%)	Water SCA 2 (%)	Water SCA 3 (%)	VRP SCA 1 (%)	VRP SCA 2 (%)	VRP SCA 3 (%)
A	0.433	0.527	0.474	0.259	0.214	0.192
B	2.474	1.010	3.591	0.139	0.091	0.120
C	1.457	1.523	1.500	0.109	0.100	0.106
D	1.707	1.466	1.494	0.101	0.107	0.094
E	1.424	1.942	1.275	0.212	2.088	0.290
F	1.552	2.006	1.428	0.254	2.662	0.215
G	1.491	1.429	1.242	0.510	1.431	0.202
H1	2.962	14.281	26.442	0.472	0.844	0.590
H2	2.836	5.386	30.754	0.493	0.861	0.603
I	1.742	1.417	1.621	0.230	0.374	0.182
O	1.954	1.532	1.567	0.730	0.323	0.220

Table 10. Relative standard deviations of detector pixel responses about a quadratic fit as a function of pixel index to the band segment response for the thermal infrared bands.

Band	Water SCA 1 (%)	Water SCA 2 (%)	Water SCA 3 (%)
J	0.251	0.175	0.203
K	0.094	0.087	0.124
L	0.236	0.135	0.267
M	0.186	0.189	0.359
N	0.096	0.573	0.230

Band calibration summaries

In addition to the overall summaries of calibration artifacts given above it is useful to identify features pertinent to individual bands. In the following discussions pixel indices will be zeros based

Band A calibration

Band A is notable for rapid variations in its response as a function of pixel index. These variations are low in amplitude, about 0.1% for the VRP and 0.25% for the water scene, but show a strong correlation over tens of pixels with the row on which the pixel located (i. e., with whether the pixel index is odd or even). Band A's SCA 3 segment shows additional larger amplitude, about 0.2% for the VRP and 0.4% for the water scene, but lower frequency (tens of pixels), oscillations. The pixel with index 1 on all three SCAs shows about a 1.9 % calibration difference with respect to the rest of the pixels in the segment. Pixels 810 and 826 on SCA 1, 532 and 578 on SCA 2, and 827 on SCA 3 show errors on from 1 % to 1.5 %. High albedo regions in band A, e.g. clouds, often have the RED_CONF value set in the corresponding quality image as they often produce radiances larger than the largest lookup table value. The ground calibration sources could not generate radiances for band A as bright as a high albedo lambertian surface reflecting solar sunlight.

Band B calibration

Band B is notable for rapid variations in its response as a function of pixel index. These variations are low in amplitude, about 0.05% for the VRP, but show a strong correlation over tens of pixels with the row on which the pixel located (i. e., with whether the pixel index is odd or even). Relative pixel to pixel variation increases by over a factor of ten for the water scene relative to the VRP. Starting with image 28537, pixel 358 on B-3 has had almost no response. Pixel 818 on SCA 2 has been considered dead since the ground calibration. The other pixels for the VRP have responsivity variations within 1%. While the problem is not as prevalent as for band A, high albedo regions in band B may have the RED_CONF value set in the corresponding quality image for the same reasons that they are generated for band A.

Band C calibration

Band C has relatively minor variations within its band segments for the VRP. Variations increase by about a factor of ten for the water scene response. Pixel 672 on SCA 1 has a response about 1% higher than the rest of the segment.

Band D calibration

Band D has relatively minor variations within its band segments for the VRP. Variations increase by about a factor of ten for the water scene response. Pixel 362 on SCA 1 has a response about 1% higher than the rest of the segment. Pixel 758 on SCA 3 is considered dead.

Band E calibration

Adjacent pixels in band E are strongly correlated in their response, but its variations over a whole band segment are larger in amplitude than for A-D, about 0.5% on SCAs 1 and 3. SCA 2 shows a large artifact, that also appears in a similar region on SCA 2 for bands F and G, over the first twenty or so pixels. This block of pixels had unusually low response compared to the rest of the band segment during the ground calibration campaign, but on orbit has shown a comparable response to the rest of the pixels in the band segment. The simplest explanation for this artifact is that there was a translucent flake of material over these pixels during the ground calibration that was removed later, possibly due to launch vibrations. Within this block of pixels the calibrated response can be more than 12% higher than the rest of the band segment.

Band F calibration

Band F’s performance in most aspects is similar to that of E, with calibrated response variations over a whole band segment of about 0.5% on SCAs 1 and 3. SCA 2 shows a large artifact, that also appears in a similar region on SCA 2 for bands E and G, over the first twenty or so pixels. Within this block of pixels the calibrated response can be more than 12% higher than the rest of the band segment. Pixel 38 on SCA 3 is considered dead in both the primary and alternate pixel rows.

Band G calibration

Band G’s performance in most aspects is similar to that of E, with calibrated response variations over a whole band segment of about, about 1% on SCA 1 and 0.5% on SCA 3. SCA 2 shows a large artifact, that also appears in a similar region on SCA 2 for bands E and F, over the first twenty or so pixels. Within this block of pixels the calibrated response can be more than 8% higher than the rest of the band segment.

Band H1 and H2 calibration

Bands H1 and H2 have a large number of artifacts. Fortunately, as they were designed for thin cirrus detection, most of these artifacts are expected to be unimportant. However in practice, the detection of thin cirrus, except in the presence of other clouds, has been rarer than expected. Bands H1 and H2 often have ghosting that is attributed to electronic cross talk. Initial operation of these bands was at extremely short integration times, to avoid saturation, resulting in noisy imagery. Subsequent operation was at longer integration times, improving the typical signal/noise ratio, but often resulting in saturation when viewing thick clouds. Their high gain, which is intended to compensate for typical low in band radiances in earth observations, makes their imagery more sensitive than other bands to short term drifts when clouds are not present. Pixel 53 on H2-2 is considered dead. In dark scenes, pixels 57, 136, and 137 on SCA 2 and 12, 13, and 14 on SCA 3, seem to be particularly prone to this problem. On SCA 1 these bands have a cyclic variation in their inferred radiances with an amplitude of about 0.7%. This is similar to cyclic variations in their responsivities that were observed in the ground calibration, and is attributed to small changes in the phase of this variation due to filter drifts on orbit.

Band I calibration

Generally band I has fewer calibration problems than many of the other solar reflection InSb bands. It has a small enhancement, about 1.5%, of its calibrated radiances near pixel 20 on SCA 2 that may be related to the much larger enhancements found in similar regions on the adjacent bands E-G on SCA 2.

Band J calibration

This discussion, and the discussion of the other thermal IR bands, K, L, M, and N, is based on the water image, 32992, which was calibrated using all three black bodies.

Band J shows small amplitude, about 0.15%, rapid variations with pixel index. On SCA 1 it shows a long wavelength, about 100 pixels, variation of about 0.3% amplitude, in its response to the water scene. On SCA 2 J shows a systematic linear trend of about +/- 1% from its first to last pixel. The linear trend on SCA 3 is correlated with other trends on the same SCA on the other thermal infrared bands, and hence is assumed to be largely due to scene non-uniformity that is not completely removed by averaging each detector’s response over all scan lines. The oscillation on SCA 1 shows weak correlation with features on the other bands.

Band K calibration

Band K has relatively few artifacts.

Band L calibration

The HgCdTe bands, L, M, and N, have more isolated outliers in their response calibrations, presumably due to on-orbit drifts, although most detector pixels are in agreement to better than 0.3%. For band L pixels 115 and 186 on SCA 1, and 71 and 173 on SCA 3, differ from the mean by more than 1%. Primary pixel 15 on SCA 3 is considered dead. The system could be reconfigured to use alternate pixel 15, at the cost of complicating the calibration of adjacent pixels.

Band M calibration

For band M pixels 189 on SCA 2 and 86, 185, 193, and 201 on SCA 3, differ from the mean by more than 1%. However, some of the detector pixels for band M have changed their properties significantly after a thermal cycle, usually worsening, but sometimes improving, e.g., a block of pixels near pixel 160 on SCA 1.

Band N calibration

For band N pixels 141 on SCA 2 and 155, and 205 on SCA 3, differ from the mean by more than 1%.

Band O calibration

Band O has a block of about twelve pixels near pixel 30 on SCA 1 with 2% to 3% lower calibrated radiances than most of the rest of band segment. Primary pixels 28, 31, and 33 on SCA 1 are considered dead. Alternate pixel 31 is considered active and the system could be configured to select it at the cost of complicating the calibration of adjacent pixels.

Registration artifacts

The “registration” artifacts strongly depend on the product. Each will be discussed separately below.

Level1b_u registration artifacts

Artifacts present in the level1b_u data product that are not found in the level1b_r_coreg product are due to the lack of registration. Obvious artifacts include:

- The “inactive” detector pixels are present in visImage_SCA#, irImage_SCA#, visQuality_SCA#, and visQuality_SCA#. Their values in visImage_SCA# and irImage_SCA# are simply replicates of the last valid detector pixel. In visQuality_SCA#, and visQuality_SCA# the corresponding values indicate that the detectors are “dead”. These data are not copied to the corresponding level1b_r_coreg images.
- The alternating of detector pixels between two rows in the Si-PIN bands causes detector pixels with odd indices in visImage_SCA# to image the same “line” on the ground at a time different from the detector pixels with even numbered indices. The interval between the time one set of pixels passes over the line and the other set of pixels passes over the line, depends on the look angle and rotation rate of the MTI satellite. The system is typically operated so that the ground sample distance (GSD) is about the instantaneous field of view (IFOV), so that the delay is equivalent to about two scan lines for the vast majority of images. However whether the odd or even pixels pass over the line last is band and SCA dependent. This artifact is automatically removed in the registration process.
- A few experimental images have both primary and alternate pixels active for some of the bands. When this occurs, the alternate pixels, in an irImage_SCA#, image the same line on the ground at different time from the primary pixels. This time delay is about one scan line in all such images acquired so far. This artifact is automatically removed in the registration process.
- Because SCA 1 is rotated 180^{o} relative to SCA 2 and SCA 3, manually registering SCA 1 to SCA 2 or SCA 3 requires transposing the detector pixel indices in SCA 1. This artifact is automatically removed in the registration process.
- The bands within an SCA are not coregistered. This artifact is reduced in the registration process.

Level1b_r_coreg registration artifacts

Registration in the level1b_r_coreg product is an automated process that estimates the ground location of each image pixel, defines the resampling grid, and resamples onto that grid.

The level1b_r_coreg product uses a variety of data to locate the image pixels on the ground as a function of time: the downlinked satellite location and pointing data as a function time, the WGS 84 ellipsoid, the orientation of the optical axis with respect to the satellite, and the angular location of each detector pixel relative to the optical axis as inferred from the focal plane geometry and ground calibration data. Every attempt is currently made to avoid additional approximations in determining this projection, but the on-orbit pointing information has an uncertainty of a few tenths of a degree, it is possible that the other input data has residual errors. No attempt at all is made to correct for topography.

The registration grid used in processing the data is defined by an SDS in the level1b_r_coreg file, frame. In current processing, frame is “orb” and a grid is defined on the ground with one axis parallel to the approximate ground track of the satellite orbit. A little used option is to have a frame of “geo” where the grid is aligned with geographic coordinates. In order to facilitate coregistering the data from other passes, the GSD for this grid for visImage is almost always the largest multiple of 5 m that is less than the effective GSD of the input level1b_u data. This criterion results in typical GSDs of 5 m for near nadir looks and 10 m for off-nadir looks. The GSD for the visLoImage and irImage is a factor of four times what it would be for the visImage. If the effective level1b_u GSD for band A-D is between 9 and 10 m, 5 m sampling may result in files that would not fit on a CD-ROM. In such cases, current processing may reduce the file size by registering to a grid that is the smallest multiple of 5 m that is greater than the effective GSD of the input level1b_u data. The true pixel size is defined by the pixsize SDS in the lebel1b_r_coreg product.

Resampling to the output grid uses a process that approximates a linear interpolation. An effective area is assigned to each pixel in the level1b_u input image and each pixel in the level1b_r_coreg grid, and the contribution of the radiance of each input pixel to each output pixel is weighted according to the fractional area of overlap of the pixels. This will be a true linear interpolation if the output grid sampling is smaller than the input GSD, the areas used in resampling were those of the product of the cross track and along track GSDs, and the imagery did not have interleaving from the alternating pixels in bands A-D (or rare alternate pixel selections). In practice, one of the areas is usually made slightly larger than that suggested by the GSD to eliminate image artifacts, possibly due to interleaving.

The most noticeable registration artifacts are:

- Band to band registration within an SCA. This error is almost entirely due to pixel location errors. The size of this error (in pixels) depends on the bands being compared, the position in the image, the look angle, and the resampling grid. Although the band to band registration error, in meters, increases with increasing distance between the bands on an SCA, the factor of four smaller pixel sizes for bands in visImage means that the error in terms of number of pixels can be larger for A relative to D in visImage, than for D (in visLoImage) relative to L (in irImage), although D and L are the most widely separated bands on the focal plane. For band A relative to band D one to two pixels near nadir misregistration is not uncommon. For band L relative to band D (in visLoImage) two or three pixels near nadir misregistration is not uncommon. Per-pixel off-nadir misregistration can be two to four times larger than near nadir.
- In-band registration between SCAs. This error is also almost entirely due to pixel location errors. The size of this error (in pixels) depends on the band being compared, the row, the look angle, and the resampling grid. Although the SCA registration error, in meters, increases with increasing distance of the band from the center off the focal plane, the error in terms of number of pixels can be larger for A in visImage, than for L, in irImage, although L is the band farthest from the center of the focal plane. For band A ten pixels SCA to SCA misregistration is not uncommon. For band L eight pixels SCA to SCA misregistration is not uncommon. Usually the SCA to SCA misregistration is larger in the cross track than in the long track direction. Per-pixel off-nadir misregistration can be two to four times larger than near nadir.

- In the areas where SCAs overlap, only the data from one SCA is shown. There is a sharp transition from one SCA to another. This can result in the loss of some data, but makes it easier to interpret the data that remains.
- Areas in the imagery outside the bounds of the band segments are filled with zeros.
- If the arrays are not aligned perpendicular to the ground track, SCA 1 overlaps with one of the other two SCAs more than the other. This effect increases with increasing distance of the band from the focal plane center. In some images for some bands SCA 1 does not overlap at all with one of the two SCAs.
- The starting and trailing edges of a band do not necessarily coincide with the starting and trailing edges of other bands. On those edges there are also artifacts in bands A-D from the alternating rows. Similar artifacts appear when an alternate pixel is selected for bands E-G, and I-O.
- The image is not aligned with latitude or longitude. A level1b_r_geo product, under development, will provide such imagery.
- The image GSD for off nadir looks need not be 5 m for visImage.
- The resampling algorithm currently used results in increased blurring relative to the level1b_u imagery.
- While we know of no example with the current code, previous versions of the resampling code would sometimes generate artifacts resembling grids, honeycombs, etc. If any such are found in recently processed imagery please let us know so that they can be used as appropriate test cases in further improving the resampling algorithm.

Contacts

Please contact the author of this text to identify any other artifacts in the imagery of interest to the general users or to suggest ways to improve this guide.

Acknowlegements

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Appendix: Distribution READMEs

README

This is the README file sent with all MTI data products produced by the MTI Data Processing and Analysis Center (DPAC) at Los Alamos National Laboratory. Please note the disclaimer listed below, which applies to all imagery produced by the MTI sensor as well as derived data products produced by the MTI DPAC.

THESE IMAGES ARE PROVIDED BY THE MTI DATA PROCESSING AND ANALYSIS CENTER (DPAC) TO BE USED ONLY BY THE RECIPIENT AND BY OTHER U.S. CITIZENS NAMED IN THE APPROVED PROPOSAL FOR SYSTEM TASKING. DO NOT FORWARD WITHOUT EXPLICIT, WRITTEN AGREEMENT OF JOHN J. SZYMANSKI, LOS ALAMOS NATIONAL LABORATORY, OR BRIAN C. BROCK, SANDIA NATIONAL LABORATORIES. PLEASE NOTE THAT MTI IS A RESEARCH AND DEVELOPMENT INSTRUMENT. THE DATA PRODUCTS ARE THE BEST AVAILABLE AT THIS TIME AND CONTINUE TO BE IMPROVED. CONSULT THE CAVEAT FILE CONTAINED IN THIS DISTRIBUTION. THANK YOU FOR YOUR COOPERATION.

The DPAC is the data processing, archive and data product documentation center for the MTI project. All MTI data products are distributed from the DPAC, and all ground-truth measurements taken in association with MTI imagery are archived at the DPAC.

Contact information:

Most of your questions concerning distribution of data products and documentation can be handled by the DPAC data analysts. The data analysts can be reached at:

mti-help@lanl.gov

or individually:

Ms. Kim Starkovich	(505) 665-0944	kstarkovich@lanl.gov
Ms. Kim Pollock	(505) 667-7609	kpollock@lanl.gov
Ms. Meg Kennison	(505) 667-8482	mkennison@lanl.gov

Contact the following people for detailed discussions of the scientific underpinnings of the data products and/or discussions of the MTI science program:

Dr. Lee Balick	(505) 665-1012	lbalick@lanl.gov
Dr. Christoph Borel	(505) 667-8972	cborel@lanl.gov
Dr. John Szymanski	(505) 665-9371	szymanski@lanl.gov

MTI data products are ordered from the MTI web site located at www.mti.lanl.gov. Access to this site is restricted to registered users. Contact the data analysts listed above to become a registered user.

MTI data products are in the Hierarchical Data Format (HDF) scientific data format. This format is in wide use on the NASA Earth Observing System and in other remote sensing programs. Note that MTI does not use the HDF-EOS extensions to the standard HDF format.

Within HDF the imagery is stored with band-sequential interleave. Below is a summary of how the band numbers in the image arrays correspond to the wavelength:

```
Visible Images (wavelengths in micrometers)
--------------
Band 1    A   0.45-0.52
Band 2    B   0.52-0.60
Band 3    C   0.62-0.68
Band 4    D   0.76-0.86

Infrared Images
--------------
Band 1    E   0.86-0.89
Band 2    F   0.91-0.97
Band 3    G   0.99-1.04
Band 4    H1  1.36-1.39
Band 5    H2  1.36-1.39
Band 6    I   1.55-1.75
Band 7    O   2.08-2.35
Band 8    J   3.50-4.10
Band 9    K   4.87-5.07
Band 10   L   8.00-8.40
Band 11   M   8.40-8.85
Band 12   N   10.2-10.7

The MTI DPAC uses the ENvironment for Visualizing Images (ENVI) as its
standard visualization package.  There is also a freeware package
related to ENVI called Freelook that allows visualization of HDF files.

ENVI information:
http://www.rsinc.com/envi/index.cfm

Freelook information:
http://www.rsinc.com/envi/freelook.cfm

HDF support is available in Fortran, C, IDL and other languages.  Most
image-processing and GIS systems import HDF data without problem.  The
following are some useful web sites for information on the HDF format
(of course, we can't guarantee that these links will always be
available):

Information on the HDF format:
http://hdf.ncsa.uiuc.edu/

Visualization packages:
http://linkwinds.jpl.nasa.gov/lwhome.html
http://www-dial.jpl.nasa.gov/
http://www-pcmdi.llnl.gov/software/vcs/index.html
ftp://ftp.ncsa.uiuc.edu/Visualization/Collage/Unix/Collage1.3/

Note that many sites also have HDF browsers available for download.
```

README_mti_header.txt

```
This file contains definitions of all the attributes in the Header file.
-----------------------------------------------------------------------

image_id:               Identifier of the specific image this header is for.

Spacecraft_ID:          String describing the spacecraft.

Request_ID:             Request ID from the tracker table in the mti_ops database
                        that was used to create the files that belong with this header.
```

Sequence_ID:	Sequence id that contains this image_id.
Sitename:	Name of the site that was imaged.
Target_ID:	A string representing the target ID assigned by SNL.
FileCreationDate:	Date the HDF header file was created.
imageStartUTC:	The start time of imaging in UTC.
imageStopUTC:	The end time of imaging in UTC.
Target_latitude:	Latitude of the imaging target (degrees).
Target_longitude:	Longitude of the imageing target (degrees).
Target_elevation:	Elevation of the target (km).
Boresight_latitude: was	Latitude (degrees) of the point on the earth where the satellite actually pointing during imaging. It is computed using data at the time midway through the image acquisition.
Boresight_longitude: was	Longitude (degrees) of the point on the earth where the satellite actually pointing during imaging. It is computed using data at the time midway through the image acquisition.
MTI_latitude: acquisition.	The latitude (degrees) of the spacecraft at the time of imaging. It is computed using data at the time midway through the image
MTI_longitude: acquisition.	The longitude (degrees) of the spacecraft at the time of imaging. It is computed using data at the time midway through the image
MTI_altitude: acquisition.	The altitude of the spacecraft at the time of imaging. (km) It is computed using data at the time midway through the image
Visible_scanlines:	If data was taken in the visible bands, the number of visible scanlines contained in the image.
IR_scanlines:	If data was taken in the IR bands, the number of IR scanlines contained in the image.
Visible_pixels:	If data was taken in the visible bands, the number of visible pixels in one scanline.
visPixsize:	Size of pixel, in meters on the ground, to which the VNIR bands (ABCD) are resampled in the coregistered image; nominally 5m, but may be larger for off-nadir imagery.
irPixsize:	Size of pixel, in meters on the ground, to which the IR image is resampled in the coregistered image; nominally 20m, but may be larger for off-nadir imagery.
IR_pixels:	If data was taken in the IR bands, the number of IR pixels in one scanline.

typical_GSD_IR_cross_track: Typical ground sample distance (that is, distance between centers of adjacent IR_cross_track detector pixels projected to the ground), in meters.

typical_GSD_IR_along_track: Typical ground sample distance (that is, distance between centers of adjacent IR_along_track detector pixels projected to the ground), in meters.

typical_GSD_VIS_cross_track: Typical ground sample distance (that is, distance between centers of adjacent VIS_cross_track detector pixels projected to the ground), in meters.

typical_GSD_VIS_along_track: Typical ground sample distance (that is, distance between centers of adjacent VIS_along_track detector pixels projected to the ground), in meters.

typical_IFOV_IR_cross_track: Typical instantaneous field of view of IR_cross_track detector pixels projected to the ground, in meters.

typical_IFOV_IR_along_track: Typical instantaneous field of view of IR_along_track detector pixels projected to the ground, in meters.

typical_IFOV_VIS_cross_track: Typical instantaneous field of view of VIS_cross_track detector pixels projected to the ground, in meters.

typical_IFOV_VIS_along_track: Typical instantaneous field of view of VIS_along_track detector pixels projected to the ground, in meters.

ActiveBands: A string listing the band names of all bands active during imaging.

ABCD_int_time: If any of bands A, B, C, or D were active, the integration time for those bands during imaging. (microseconds)

EGIO_int_time: If any of bands E, G, I, or O were active, the integration time for those bands during imaging. (microseconds)

F_int_time: If band F was active, the integration time for band F during imaging. (microseconds)

H_int_time: If band H was active, the integration time for band H during imaging. (microseconds)

J_int_time: If band J was active, the integration time for band J during imaging. (microseconds)

K_int_time: If band K was active, the integration time for band K during imaging. (microseconds)

LMN_int_time: If any of bands L, M, or N were active, the integration time for those bands during imaging. (microseconds)

ReadStep: A float array of (active bands, active scas) containing the readStep time for each band/sca. (seconds)

Master_scan_clock: Represents one tick of the master scan clock.

FPA_temp1: The focal plane assembly temperature taken by the low resolution (110V) sensor. (Kelvin)

FPA_temp2: The focal plane assembly temperature taken by the high resolution (300V) sensor. (Kelvin)

azimuth2MTI: The direction on the earths surface from the target (image center) to the subsatellite point on the earth. The directional component of the vector from the target to the satellite. (Values are in decimal degrees)

zenith2MTI: The angle between the target (image center) zenith and the line to the satellite as measured from the target. (Values are in decimal degrees)

nadir2scene: The angle between the satellite nadir and the line from the satellite to the target (image center), as measured from the satellite. (Values are in decimal degrees)

scene_shear: The angle between the cross track and the along track directions (decimal degrees). 90 degrees corresponds to a nominal square image.

alongtrack_direction: Angle in degrees E of N of the along track motion of the boresight on the ground.

crosstrack_direction: Angle in degrees E of N of a projection of a line of pixels onto the ground.

image_orientation: Angle in degrees E of N of a vertical vector on the coreg image.

solar_azimuth: The direction from the target (image center) to the subsolar point on the earth. The directional component of the vector from the target to the sun. Angles increase clockwise from north, 0 to 360 degrees. (Values are in decimal degrees)

solar_elevation: The angle of the sun above a horizontal plane at the target (image center) (Values are in decimal degrees)

daylight: An indicator of 'T' (true) or 'F' (false) of whether the image was taken in daylight.

Projection: Type of map projection used in the geolocation. There are several ways and different types of projections used when projecting a 3D surface to a 2D one. Example: Polar Stereographic, Mercator, etc.

Ellipsoid: String. Mathematical model of earth.

Geolocation_model: The mathematical/theoretical model used for geolocation.

Datum: String. The model of the earth's shape as approximated by an oblate spheroid upon which the planimetric coordinate system is based (e.g., "WGS-84").

Coord_system: String. Describes the cartesian coordinate system used to express the planimetric location of features within an image. If a zone parameter is required, the zone is part of this descriptions. The coordinate system is based on a particular projection, datum (ellipsoid), and linear distance unit (e.g., UTM Zone 16 North).

Linear_dist_unit: String. The physical unit of distance used by the coordinate system.

Quality_ID: The quality code assigned to the image by a data analyst.

upper_left_y: Upper left corner image UTM northing coordinate(1st pixel).

upper_left_x: Upper left corner image UTM easting coordinate(1st pixel).

lower_right_y: Lower right corner image UTM northing coordinate(last pixel).

lower_right_x: Lower right corner image UTM easting coordinate(last pixel).

README_level1b_r_coreg.txt

```
This readme file contains definitions of attributes in the level1b_r_coreg
hdf file.
--------------------------------------------------------------------------------

image_id:              Long. Unique identifier of the image.

activeBands:           Byte array containing a flag for each band
                       (16x3) indicating if the band is active for
                       this look.  1=Active 0=Inactive

visImage:              Float array (pixels, scanlines, bands) for all
                       bands (even inactive ones) in band averaged
                       radiance for the registered image.
                       See end of this document for a discussion of band
                       averaged radiance(*).
                       (Watts/meter^2/steradian/micron)

visLoImage:            Float array (pixels, scanlines, bands) for all
                       bands (even inactive ones) in band averaged
                       radiance for the registered image(*).
                       (Watts/meter^2/steradian/micron)

irImage:               Float array (pixels, scanlines, bands) for all
                       bands (even inactive ones) in band averaged
                       radiance for the registered image(*).
                       (Watts/meter^2/steradian/micron)

  (For the following 3 attributes pixelState is defined as:
   pixelState = { pixelstate,        $
                  saturated:     '01'xb,  $
                  extrapolated:  '02'xb,  $
                  missing:       '04'xb,  $
                  dead:          '08'xb,  $
                  uncalibrated:  '10'xb,  $
                  other:         '20'xb  $
             })
vis_lo_quality:        Byte array (pixels, scanlines, bands) for all
                       bands (even inactive ones) containing the pixelState.

vis_quality:           Byte array (pixels, scanlines, bands) for all
                       bands (even inactive ones) containing the pixelState.
```

ir_quality: Byte array (pixels, scanlines, bands) for all bands (even inactive ones) containing the pixelState.

imageType: 3-character abbreviation for the type of image.

roll: Double. The spacecraft roll angle in degrees.

pitch: Double. The spacecraft pitch angle in degrees.

yaw: Double. The spacecraft yaw angle in degrees.

gps_times: An array of unix_times that correspond the positions and velocity values.

position: An array of xyz spacecraft coordinates (ECI, meters) as a function of time.

velocity: An array of spacecraft velocity vectors (ECI, meters/second) as a function of time.

quaternions: An array of spacecraft quaternions as a function of time.

quat_times: An array of unix times that correspond to the quaternion values.

altitude: Float. Altitude of the spacecraft. (kilometers)

grnd_speed: Float. Ground speed of the spacecraft. (meters/second)

daylight: 1-character. 'T' or 'F' to indicate whether or not image taken during daylight.

solar_elevation: The angle of the sun above a horizontal plane at the target (image center). (Values are in decimal degrees)

solar_azimuth: The direction from the target (image center) to the subsolar point on the earth. The directional component of the vector from the target to the sun. Angles increase clockwise from north, 0 to 360 degrees. (Values are in decimal degrees)

zenith2mti: The angle between the target (image center) zenith and the line to the satellite as measured from the target. (Values are in decimal degrees)

azimuth2mti: The direction on the earths surface from the target (image center) to the subsatellite point on the earth. The directional component of the vector from the target to the satellite. (Values are in decimal degrees)

boresight_lat: Latitude (degrees) of the point on the earth where the satellite was actually pointing during imaging. It is computed using data at the time midway through the image acquisition.

boresight_lon: Longitude (degrees) of the point on the earth where the satellite was actually pointing during imaging. It is computed using data at the time midway through the image acquisition.

MTI_latitude: The latitude (degrees) of the spacecraft at the time of imaging. It is computed using data at the time midway through the image acquisition.

MTI_longitude: The longitude (degrees) of the spacecraft at the time of imaging. It is computed using data at the time midway through the image acquisition.

nadir2scene: The angle between the satellite nadir and the line from the satellite to the target (image center), as measured from the satellite. (Values are in decimal degrees)

scene_shear: The angle between the cross track and the along track directions (decimal degrees). 90 degrees corresponds to a nominal square image. (crosstrack_direction - alongtrack_direction)

alongtrack_direction: Angle, in decimal degrees clockwise from vertical, of the average alongtrack motion in the coregistered image. Note: for frame='orb' images, this angle is very nearly zero.

crosstrack_direction: Angle, in decimal degrees clockwise from vertical, of a line of detector pixels projected to the ground, and observed on the coregistered image.

image_orientation: Angle, in decimal degrees clockwise from vertical, of the North-pointing vector on the coregistered image. Note: for frame='geo' images, this angle is very nearly zero. For frame='orb' images in the northern hemisphere, this angle is generally small and positive (of order ten degrees) in the daytime, and of order 170 degrees at night.

pointing: Pointer to ground pointing information for the image.

Rsat: Pointer to an array of values containing the position of the satelitte (in kilometers) in ground frame coordinates as a funtion of time in ticks.

Qsat: Pointer to an array of values containing the orientation of the satellite (quaternion:l2f) as a function of tick time.

frame: String which specifies the coordinate frame to which the data are resampled ('orb' or 'geo').

extent: Float array(4). Extent of the data. For the 'geo' frame data, this will be approximate UTM coordinates.

utm_lat_zone: String (single alphabetic character).

utm_lon_zone: Integer. Specifies which UTM zone the image is in.

affine: Float array (6). Specifies the affine transform that was applied to the coreg data.

level1b_r_coreg_revision: String representing the revision of the registration pipeline.

level0_revision: String representing the revision of the level0 pipeline.

level1b_u_revision: String representing the revision of the calibration pipeline.

pixSize: Size of pixel, in meters on the ground, to which the IR image is resampled in the coregistered image; nominally 20m, but may be larger for off-nadir imagery.

visPixSize: Size of pixel, in meters on the ground, to which the VNIR bands (ABCD) are resampled in the coregistered image; nominally 5m, but may be larger for off-nadir imagery.

typical_GSD_IR_cross_track: Typical ground sample distance (that is, distance between centers of adjacent IR_cross_track detector pixels projected to the ground), in meters.

typical_GSD_IR_along_track: Typical ground sample distance (that is, distance between centers of adjacent IR_along_track detector pixels projected to the ground), in meters.

typical_GSD_VIS_cross_track: Typical ground sample distance (that is, distance between centers of adjacent VIS_cross_track detector pixels projected to the ground), in meters.

typical_GSD_VIS_along_track: Typical ground sample distance (that is, distance between centers of adjacent VIS_along_track detector pixels projected to the ground), in meters.

typical_IFOV_IR_cross_track: Typical instantaneous field of view of IR_cross_track detector pixels projected to the ground, in meters.

typical_IFOV_IR_along_track: Typical instantaneous field of view of IR_along_track detector pixels projected to the ground, in meters.

typical_IFOV_VIS_cross_track: Typical instantaneous field of view of VIS_cross_track detector pixels projected to the ground, in meters.

typical_IFOV_VIS_along_track: Typical instantaneous field of view of VIS_along_track detector pixels projected to the ground, in meters.

*Note - A discussion of band averaged radiance as it applies to MTI follows:

1.) A general definition of band averaged radiance is:
The ratio of the integral over wavelength of the input radiance with system spectral response to the integral over wavelength of the system spectral response.

2.) For MTI, we are currently approximating the system spectral response as the filter transmittance so a more accurate definition for MTI is:
a) The ratio of the integral over wavelength of the input radiance with filter transmission to the integral over wavelength of the filter transmission.

- or even pickier:
b) The ratio of the integral over wavelength of the input radiance with filter transmission to the effective filter bandwidth, where the effective filter bandwidth is the integral over wavelength of the filter transmission.

READLME_level1b_u.txt

This readme file contains definitions of attributes in the level1b_sir hdf file.

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image_id:	Long. Unique identifier of the image.
activeBands:	Byte array containing a flag for each band (16x3) indicating if the band is active for this look. 1=Active 0=Inactive
visImage:	Float array (pixels, scanlines, bands) for all bands (even inactive ones) in band averaged radiance for the registered image. See end of this document for a discussion of band averaged radiance(*). (Watts/meter^2/steradian/micron)
vis20:	Float array (pixels, scanlines, bands) for all bands (even inactive ones) in band averaged radiance for the registered image(*). (Watts/meter^2/steradian/micron)
irImage:	Float array (pixels, scanlines, bands) for all bands (even inactive ones) in band averaged radiance for the registered image(*). (Watts/meter^2/steradian/micron)
imageType:	3-character abbreviation for the type of image.
level1b_r_coreg_revision:	String representing the revision of the registration pipeline.
level0_revision:	String representing the revision of the level0 pipeline.
level1b_u_revision:	String representing the revision of the calibration pipeline.

*Note - A discussion of band averaged radiance as it applies to MTI follows:

1.) A general definition of band averaged radiance is:
The ratio of the integral over wavelength of the input radiance with system spectral response to the integral over wavelength of the system spectral response.

2.) For MTI, we are currently approximating the system spectral response as the filter transmittance so a more accurate definition for MTI is:

a) The ratio of the integral over wavelength of the input radiance with filter transmission to the integral over wavelength of the filter transmission.

- or even pickier:

b) The ratio of the integral over wavelength of the input radiance with filter transmission to the effective filter bandwidth, where the effective filter bandwidth is the integral over wavelength of the filter transmission.